SCIENCE

FRIDAY, FEBRUARY 20, 1914

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE PLEISTOCENE HISTORY OF THE MISSOURI RIVER[1]

ASSUMING that one whom you may honor by election to this position of vice-president is expected to bring forward something concerning his special line of research, I have chosen the theme presented as my subject. It has been my lot to study more or less for the last forty years the relations of the Missouri River to the Pleistocene Ice.

This paper proposes to set forth some facts, some of them not widely known, with theories for their explanation, and to interweave the theories with sufficient speculation to form a consistent and not improbable story.

My personal examination covers only from the mouth of the Missouri to Bismarck, N. D., consequently I speak less intelligently of the region farther north.

The Missouri is not an old river geologically speaking. It has reached maturity over most of its course, but that is the result of the softness of the rocks over which it flows, rather than of the length of time it has occupied its present course. Nor is the degree of maturity proportionate to the softness of the rocks. For example, through the Dakotas it is in very early maturity, the flood plains are narrow and the trough is narrow and has steep sides, though the rocks are very soft, while in its lower course the breadth of its trough is quite strictly proportional to the softness of the rocks forming the bed of the present

[1] Address of the vice-president and chairman of Section E, Geology and Geography, American Association for the Advancement of Science, Atlanta, December 29, 1913.

stream. This indicates that the upper part of its present source is younger in time.[2]

The fact has long been recognized that the Ohio and Missouri rivers mark approximately the southern limit of the great ice sheet of the Pleistocene, as though the latter had exercised a controlling influence in the courses of the former. The Ohio, being more accessible, has been studied by several geologists, but by none more carefully than by Professor W. G. Tight.[3]

There the general preglacial drainage was toward the northwest and was changed to the southwest. In the case before us we shall find reason to believe the preglacial

[2] Missouri Geol. Survey, Vol X., Pl. XX., and U. S. G. S. Bull. 158, Pl. XXIII.

[3] Professional Paper No. 13, U. S. G. S. (1903), "Drainage Modifications in Southeastern Ohio and Vicinity."

drainage was largely to the northeast and the ice changed it to the southeast.

The exceptional or anomalous course of the present Missouri is shown by the following facts. The Missouri at Ft. Stevenson, where it turns sharply to the southeast, is 1,720 feet A. T., while the Souris River, forty miles northeast, is 200 feet lower and from there is an open course to Hudson Bay, 900 miles away in a straight line. Instead of finding its way thither it reaches the Gulf of Mexico at just about twice that distance. To be sure other rivers show similar eccentricities, but they have mountain ranges to explain their action. Here there is nothing of that sort, but, on the contrary, only soft rocks lying horizontally. Moreover, the tendency for the Missouri to run at right angles to the direction of slope is shown further by the following facts: at Bismarck it is 220 feet higher than the James River at Jamestown, 105 miles east, and 400 feet above the Chyenne, 10 miles further east; at Pierre it is about 200 feet above the James, 105 miles east, and at Chamberlain 100 feet higher than the James near Mitchell, 66 miles east. At Sioux City the Missouri is 130 feet higher than the Des Moines at Ft. Dodge, 110 miles away, and at Council Bluffs 200 feet higher than the Des Moines, 115 miles east. At Kansas City it is about 300 feet higher than the Mississippi at Hannibal, about 200 miles east. This illustrates strikingly the tendency of the Missouri to follow the strike of the surface rather than the dip.

This anomaly is commonly ascribed to the influence of Pleistocene ice sheets. In general it is safe to suspect that the preglacial drainage of the region was toward the east or northeast. This agrees with the fact that streams along the line of the present Missouri trend eastward, except in the vicinity of glacial deposits, viz., from the vicinity of Williston, N. D., to Kansas City, Missouri.

A. THE PROBABLE PRE-PLEISTOCENE DRAINAGE ALONG THE LINE OF THE PRESENT MISSOURI RIVER

The conclusions offered here should be valued carefully according to their weight. Some may be considered fairly established; others are given only provisionally. Moreover time permits us to indicate them only briefly without stating them so fully as might be desired. The main tributaries of the Missouri are from the west and have uniformly a persistently eastward direction. Furthermore, they may be grouped into clusters of two or three which converge as they approach the Missouri, and in several cases corresponding valleys are discoverable east of the Missouri. We will consider these groups in order.

1. *The Missouri and Little Missouri Rivers.*—The upper Missouri keeps a quite persistent easterly course from the mountains till it approaches the glacial drift near Nesson, N. D. The Yellowstone flowing northward joins it 40 miles west at Buford. The Little Missouri, with a course parallel to the latter, formerly joined the Missouri at Nesson, but now it leaves its old channel about 50 miles south of its old mouth, turns east and joins the present Missouri near Ft. Berthold. In view of these facts, probably the first suggestion which comes to mind is, that before the Pleistocene the Little Missouri joined the Missouri at Nesson and both continued their way eastward to the bend of Souris River and thereby reached Hudson Bay. This seems to agree with the fact that a terrace and old channel more than 100 feet higher than the present river leads eastward over a dozen miles into the morainic drift, but such a conclusion is forbidden by the discovery of a channel corresponding in height and size several

miles southeast leading across a large bend of the Missouri in a southeast direction. This seems to show quite clearly that the Missouri occupied this channel before the ice came. If this was true it is probable that the river continued south of east to Ft. Stevenson, where the present stream turns sharply southward. Knife River joins it several miles further south, and from the direction of the valleys and the fact that there is an unusually large valley for a small stream, Snake Creek, coming in from the northeast at Ft. Stevenson, it seems possible that the Knife and Missouri formerly joined near Ft. Stevenson and ran northeast to the Souris. The divide between is heavily covered with drift and we know nothing of the preglacial surface below, but some maps show a deep notch in the east front of the divide nearly north from Ft. Stevenson and in line with the northeast course of the Souris on the south side of its great bend. The height of the Missouri at Stevenson is close to 1,700 feet A. T.; of the Souris, 45 miles away, is about 1,500 A. T.; the height of the divide between, not less than 2,100 A. T. The altitude of the terrace at Ft. Stevenson is about 1,790, which would indicate that the old channel, if there, is filled at least 230 feet with drift, which is no uncommon thickness.

The Souris at present is several feet below the bottom of the drift there, and 50 to 75 feet below the level of the Souris plain of Lacustrine origin. The surprisingly low altitude of the Souris compared with that of the Missouri is most reasonably explained by great glacial erosion of the soft rocks underlying the region. The preglacial drainage doubtless had a much gentler slope than the present surface would indicate.

2. *The Heart and Cannon Ball Rivers.*—The Heart River joins the Missouri at Bismarck at 1,620 A. T. It shows a conspicuous terrace west of Mandan, which rises 110 feet higher. Southeast of Bismarck a terrace and broad valley-like depression runs up Apple Creek to Menoken, 15 miles east, then southeast as much further, to the southwest end of Long Lake. Its bottom fluctuates a little above and below 1,750 A. T. Cannon Ball River joins the Missouri about 30 miles south of Bismarck, opposite the mouth of Long Lake Creek, which drains a valley running north-northeast, in line with the lower course of Cannon Ball to the west end of Long Lake, and to the valley already mentioned as coming from Bismarck. Long Lake occupies a valley 25 to 30 miles long and 4 or 5 miles wide, continuing in the same direction, past Dawson, on the Northern Pacific railway, until it becomes filled with glacial deposits and untraceable. The altitude of the bottom of the valley near Dawson is 1,738 A. T. A lobe of the ice of the Wisconsin stage pushed up this valley as far west as Sterling. We have, therefore, quite convincing evidence that Heart and Cannon Ball rivers, at some time, most probably in preglacial times, flowed over the present divide between the Missouri and James rivers. Their course further east has been obliterated by the marked erosion and deposition of the various ice sheets, which have successively occupied the region further east.

3. *Grand and Moreau Rivers.*—The Grand River turns southeast before reaching the Missouri, apparently to go around the south end of a high ridge which lies just east of the latter stream. The Moreau probably joined it near this point not far from Mobridge. Both streams have several terraces along their valleys; those about 200 feet above the present stream are prominent and correspond to a broad valley which runs northeast 20 to 25 miles, where the surface becomes morainic and

rises gradually to the lowest point of the divide below the Missouri and James near Hillsview, at an altitude of 1,850 A. T. Thence is a gradual descent to the valley of the James near Aberdeen. That the axis of a lobe of ice lay along this line during the Wisconsin stage is shown by hills lying to the north and south, and these with the before mentioned ridge lying along the east side of the Missouri are all covered with morainic drift. It is not difficult to conceive that the preglacial Grand and Moreau, flowing 200 to 250 feet higher than now, went east to the James.

4. *Cheyenne and Bad Rivers.*—These constitute another pair which, probably uniting near Pierre, passed east to the James River Valley. The Cheyenne at that time lay further south in its lower course, as is indicated by broad high terraces. It passed south of Sully Buttes and eastward through the northern part of Hyde and Hand counties and the valley of Turtle Creek to the James near Redfield. Bad River may have joined it near the mouth of Okobojo Creek or may have followed the present course of the Missouri to the mouth of Medicine Knoll Creek and up its course to a junction in eastern Sully county. There is similar and clearer evidence of a former ice lobe here than that found in the last case, viz., the moraines to the north and south and along the east bluffs of the Missouri. The valley is so well marked that it is popularly known as the Ree Valley. The hills north and south rise to 2,000 A. T. The lowest part of the divide in the valley is 1,650 to 1,675 A. T. The depth of the glacial drift may reach 200 to 250 feet.

5. *White River.*—The course of this river is about as easily traceable east of the Missouri as that of Heart River, and for a similar reason, viz., because the ice did not quite reach to the Missouri in its valley. There are several prominent terraces along White River, one 200 to 250 feet above the stream. At about the same level is a valley about two miles wide which runs from the mouth of that river northeast nearly 25 miles, where it is crossed by a moraine a little west of White Lake. White Lake may be considered in it and the depression continues down the Firesteel to the James, and then northward to join the Cheyenne. Red Lake occupies a portion of this same valley. Several miles south of White River is the old divide between it and Niobrara River. It stands out prominently as a high range of flat-topped buttes capped with Tertiary sandstone. The gorge of the Missouri through it is 750 feet deep. The preceding rivers after reaching the James Valley, which was then imperfectly developed, converged to a point northeast of Aberdeen, where there is a prominent gap in the highland east of the James, a little north of the south line of North Dakota. It is the wide valley of an intermittent stream called the Wild Rice River. That stream heads close to the James River and the divide between is not over 30 feet higher than the latter. The Wild Rice descends 300 feet in 60 miles and joins the Red River of the North.

We may conclude, therefore, that White River turned northward, joined the Cheyenne near Redfield and Grand River north of Aberdeen and met the Cannon Ball and Heart rivers coming from the north and all formed an important stream which found its way eventually to Hudson Bay, as Red River does to-day. It is possible that the two from the north may have found courses along the Cheyenne and not joined those from the south till later. No trace of the old courses could be found now, for the erosion of the Pleistocene must have lowered the surface scores of feet below the bottoms of the old valleys.

6. *Niobrara River.*—The valley of this

stream as late as just before the Wisconsin stage of the Pleistocene has been clearly traced from a little south of its present junction with the Missouri, northeast past Springfield and Tabor, to the James a few miles northeast of Yankton. There is little doubt that its preglacial course was the same so far. Its altitude was probably 100 to 150 feet above the present, *i. e.*, 1,300 to 1,350 A. T. It may have been 100 feet higher still. That it belonged to a different system from those hitherto considered is favored by the following facts: (1) there is trace of an old divide crossing the James River south of Mitchell. The Sioux Quartzite rises to more than 1,200 A. T. and Cretaceous rocks overlive to a height of more than 1,300. As this is in the center of the valley it is reasonable to think that 100 feet may have been carried away by glacial erosion. (2) There is a line of high ridges lying across the James valley north of the Niobrara, as though they were a remnant of a divide. I refer to the Choteau Creek Hills, James Ridge and Turkey Ridge. (3) The few traces of preglacial surface in eastern Nebraska and western Iowa seem to call for a lower drainage level than is indicated farther north, and also farther south. In short there seems to be need of finding a drainage outlet eastward to the Des Moines, or else to postulate a recently formed syncline for which we know no other evidence.

We conclude therefore that the Niobrara turned south and followed the courses of the James and Missouri to the vicinity of Onawa, Iowa, thence east and northeast through Ida and Sac counties past Wall Lake and thence southeast along the Raccoon River.

This conclusion rests on a few apparently reliable reports from wells which show that the preglacial surface indicates a valley whose bottom is less than 900 A. T., in some cases less than 850. It has not been possible to outline the valley throughout, but half a dozen observations through Ida and Sac counties are most easily explained by such a theory. The fact that Wall lake lying on the summit formerly drained into Boyer River and now into the Raccoon, and another fact that the Boyer rises east of the crest of the divide, has first a course east of south and at this point turns southwest, are also most easily explained by the theory given.

There was a descent of about 350 feet from Sioux City to Wall Lake.

7. *Platte River of Nebraska.*—This stream presents difficulties which have not yet been satisfactorily solved. The lowest surface overlain with glacial deposits in their original position seems to be about 970 feet A. T. in the vicinity of Omaha and Council Bluffs. The lowest striated rock surface is about 1,000 A. T., except a ledge at Omaha reported by Dr. C. A. White, which was about 6 feet above the river, and may have been the result of the action of river ice. It is conceivable that till may have slumped 30 feet into more recent excavations without clearly showing the fact. There are numerous evidences of such slumping elsewhere along the trough of the Missouri.

Now there seems to be quite clear evidence, as will be explained in the next section, that in early Pleistocene there was a divide at least 900 feet A. T. near Leavenworth and that south of it drainage levels were considerably higher than north of it. There would, therefore, have been insufficient slope in that direction to have excavated down to 970 feet A. T. 150 miles away. We seem driven therefore to find some other outlet.

Could it have been through to the Des Moines by the old channel in Sac county? That would have had a steeper grade than by Leavenworth. We have not been able

to find any other route to the Des Moines half as probable, but it has been argued elsewhere[4] that eastern Iowa was formerly relatively considerably higher than now.

Could it have been southeast to the Grand River of Missouri? From the mouth of Platte River to a point in Grand River of equal altitude to the Missouri at Leavenworth is considerably shorter than to the latter point. It is quite possible that Grand River was not much higher in preglacial time than now. The region has not been examined with reference to this problem, but there is nothing in the course of present streams nor anything reported concerning the geology of that region which suggests that the Platte ever followed that course. We must therefore leave the problem not definitely solved, though the second hypothesis seems on the whole the more probable.

8. *Kansas River.*—The preglacial course of this stream is known to have followed nearly its present course but from 125 to 150 feet higher than now. This is shown by stretches of chert gravels with no admixture of northern erratics, such as the glaciers brought into the region. We may conceive that it followed the course of the Missouri from Kansas City to the vicinity of Miami and thence southeast by Salt Fork to the Lamine River and back to the Missouri again. If the Platte reached Grand River it would here have joined the Kansas.

From the distribution of the drift and loess in Missouri I argued some years ago[5] that the Osage in early Pleistocene did not join the Gasconade but turned north by the present course of Auxvasse Creek and over into Salt River and so to the Mississippi. It does not seem very probable, though not clearly forbidden by known facts. The upland between rises to 870, and there is no trace of divide between the Osage and the Gasconade, nor are they different in depth and age, as we should expect, if they had been separated till recently. The other alternative is to suppose that its course was down the present Missouri to its mouth, and that the shallow valley along the line of the Auxvasse and Salt Fork is due to general erosion acting on softer rocks, rather than to the presence of a master stream.

[4] *Kan. Univ. Sci. Bull.*, Vol. VI., p. 375.

[5] Mo. Geol. Survey, Vol. X., pp. 200 and 212.

B. THE MISSOURI DURING THE NEBRASKAN STAGE

We now proceed to consider the probable history of the Missouri during the successive stages of the Ice Sheet of the Pleistocene. The stages usually recognized are in order: Nebraskan, Kansan, Illinoian, Iowan and Wisconsin, with substages of the last Altamont, Gary Antelope, etc., corresponding to the principal moraines left.

We know little of the Nebraskan Stage except that the ice did not then extend so far as the Kansan and that its deposits have been mostly carried away or hidden by the ice of the latter stage. The ice advancing from the north gradually pressed southward up the Red River valley, and dammed the master stream, formed of the streams we have enumerated as flowing northeast from the present James River valley, and caused an overflow into the Des Moines valley. Later it closed up their entrance into the Red River valley from the west, and caused the Missouri, Cannon Ball, Grand and Cheyenne to become a lake, and to overflow whatever divide separated them from White River, and eventually to overflow the divide separating them from the Niobrara, outlining for the first time the course of the James River.

Meanwhile, the ice passed more freely southward in the Des Moines valley, filling it and forcing the Niobrara to overflow what ever divide separated it from the

Platte, and compelling all the streams mentioned to find their way around the edge of the ice southward, probably along the line of the present Missouri, or a little west of it, from Sioux City to Nebraska City and quite likely for a time through the Grand River of Missouri.

We are assured that the ice entered eastern Nebraska and reached to the south line of Iowa. In Dakota, it probably did not enter the James River valley extensively, for the gap by which it entered was probably narrow and its axis at right angles to the lobe which filled the Red River and Des Moines valleys.

C. THE MISSOURI DURING THE KANSAN STAGE

After a recession, we know not how far back, the ice advanced again to its maximum extent. The ice filled the Des Moines valley again, and overflowed southward to central Missouri, westward to Lincoln, Neb., and southwest to Topeka, Kan. As it crowded the great stream which skirted its edge, for the first time it overflowed the divide separating it from the Kansas, at Weston, Mo., a little north of Leavenworth. This fact is recorded in a stratum of boulders, nearly 20 feet thick and extending for miles along the bluffs east of the river. It rests on Carboniferous shales which rise about 140 feet above the present river. Among the boulders are scattering ones of northern origin attesting the vicinity of the ice sheet. Of course, when the ice reached Topeka, that locality of Weston was deeply buried with ice, and the master stream was forced much farther westward, as we shall see.

Meanwhile, the lobe entering the James River valley found, no doubt, a freer access because of the erosive work of the earlier ice lobe and of the streams attending it, for they worked on soft material. The latter must have been quite large, for they drained the western edge of the ice quite extensively. Besides, the head of the ice behind was probably higher than before and the push forward stronger. Moreover, because of the latter condition, the ice overrode the divide to the north more, and the push was more southward than before, so that in this Kansan stage the Dakota ice lobe reached perhaps as far south and west as West Point, Neb., and became confluent with the west edge of the Minnesota-Des Moines lobe for hundreds of miles.

As the ice advanced in the James River valley the surrounding streams had to shift laterally westward and when dammed rose and overflowed local divides, working their way southward around the ice. The Missouri River entering the James River valley from the north, probably with the Souris, skirted the western edge of the ice, through the Dakotas to the Niobrara, being successively augmented by the various streams before mentioned from the west. Reaching the Niobrara it first followed it eastward to the vicinity of Sioux City, but later as the Dakota lobe crowded against the highlands of northeastern Nebraska, the river was choked off and, being dammed, it formed a deep lake, reaching far north along the western edge of the ice and eventually overflowed southward from the south bend of the Niobrara, past Creighton and Plainview, where the channel is still traceable, to the Elkhorn.

So also farther south, the stream was pushed westward by the advance of the Kansan ice from the former course along the east line of Nebraska, to a line along Logan, Elkhorn and Platte rivers, and possibly for a short time over the divide into the Nemaha to its earlier course through Missouri.

But eventually when the ice reached its maximum, the stream from the Niobrara before sketched crossed the line of the Elk-

horn at Norfolk, went up Taylor Creek, over the divide south at Creston, to the Platte, and over the divide south of that, near or east of David City, into the Big Blue. From there the course is clear.

The course from the Elkhorn to the Big Blue is largely conjectural. There may have been no distinct channel much of the way, for any considerable time. Drift deposits in Nebraska seem more than usually of a stratified or banded character especially toward the margin. There may have been extensive shallow lakes over much of the way.

Some present altitudes along this course will be instructive. Through the Dakotas, the altitude may have been 1,600 to 1,700 feet; Plainview is 1,683, Norfolk, on the Elkhorn, 1,525; Creston, 1,604; Schuyler on the Platte, 1,350; David City, 1,607; Millerton, on the Big Blue, 1,590. It may possibly have reached the Big Blue by Skull Creek and Oak Creek passing a little west of Lincoln and over the divide near Berks, without finding an altitude over 1,500 A. T.

After reaching the Big Blue the course was clear. The course was unobstructed to the Kansas at Manhattan, Kan., and eastward by the latter stream around the ice to the Mississippi. So at first, but as the ice continued southward it for a time dammed the Big Blue, a little below Blue Rapids, Kan., forming a short-lived lake which covered the eastern half of Washington county, Kan., and possibly at about the same time formed a similar lake, Kaw Lake as it has been called, in the valley of Kansas River, by filling the trough of that stream with ice from Wamego to Lecompton, a distance of more than sixty miles. Kaw Lake, soon filled and found an outlet over the divide south 200 feet higher than the present stream, and from the valley of one small tributary of the Kansas to another, till southeast of Topeka it reached the valley of the Wakarusa, which conveyed it around to the valley of the Kansas below the barrier. At Kansas City the ice sheet crowded against the heavy limestone ledges in the northern part of the city, while the river occupied the valley in the southern part of the city, which leads eastward to the Missouri again.

This course was occupied through Kansas long enough to cut down quite a channel and to pave it with boulders and gravel, before the recession of the ice opened up the channel of the Kansas again.

D. WHILE THE KANSAN ICE WAS RECEDING

Though the ice sheet of the Kansan stage seems not to have paused in any one position long enough to form a marginal moraine anywhere, its advance and recession must have been very slow. After the Kansas resumed its preglacial course it cut down considerably before it ceased to receive the drainage of the ice, or before main drainage of the ice had shifted back to the line of the present Missouri, south of Dakota.

Omitting many details that might be given in the progress of shifting, I will simply give one which has been studied.

When the Kansan ice was at its maximum, the master stream of drainage flowed past Plainview at an altitude of 1,683. As the ice receded to the east and north the stream found a way at a lower level along the edge of the ice for several miles and then over the divide at Coleridge at 1,552, and then down Logan Creek. This allowed the rapid lowering of the water in the temporary lake in the Niobrara, and caused the deposition of much gravel along the line. As the ice receded farther the stream followed the ice front till it reached the line of the former course of the Niobrara, which passed northeast from its present

junction with the Missouri and joined the James several miles north of Yankton.[6]

At this point we may offer a word concerning the loess. This problematic deposit covers the Kansan till almost universally. The surface of the latter is generally much eroded, and because of this it has been argued that a long time elapsed between the deposition of the two formations. It was once claimed that the loess was largely of Iowan age, but it can be reasonably questioned whether erosion might not have been rapidly accomplished by the waters closely attending the edge of the ice, while the loess may have been deposited in flooded streams and local lakes remote from the edge. This silty material has doubtless been further modified by wind action and by later erosion and slumping. A strong objection to the flood theory, formerly felt, was the supposition that the channels of that time were as deep as the present, which we have seen was not the case. The drainage level of Kansan time was from 80 to 120 feet higher than that of the present, and it would have required scarcely a higher rise of water to have overflowed the uplands of that time than that which we shall find attended the retreat of the Wisconsin ice sheet.

E. FROM THE END OF THE KANSAN STAGE TO THE BEGINNING OF THE WISCONSIN

This was a long time during which the ice occupation of the region under consideration was not conspicuous. It corresponds to the Illinoian and Iowan advances and secessions of the ice. Elsewhere the ice found a growth into southern Illinois and far enough into southeastern Iowa to push the Mississippi westward nearly forty miles, then a recession and an advance from the northwest in eastern Iowa till the Mississippi was pushed eastward over into Rock River.

Meanwhile the ice may have lingered in northern Minnesota and Dakota and have caused greater volume to the streams than now. The course of the master stream was doubtless in the James valley approximately along the course of the present James River, and further south along the present Missouri. Erosion deepened all channels, till their bottoms approached the level of the present surfaces of the streams. The valleys were widened considerably, particularly in the soft Cretaceous formations in the Dakotas and northwestern Iowa.

F. DURING THE ADVANCE OF THE WISCONSIN ICE

As in earlier stages the Minnesota and Dakota lobes of ice were the only ones advanced southward along the same lines which affected seriously the Missouri. They advanced southward along the same lines as before, and though probably with greater velocity and vigor, yet they did not attain so great extent. This may be explained possibly by a warmer climate than in former advances. The Minnesota lobe reached only to Des Moines, Iowa. The Dakota lobe only to the south line of South Dakota, although it pushed farther westward than before up the valleys of the western tributaries. Why this should be is not very evident. Possibly because of the greater depth and width of the trough of the Niobrara River where it was transverse to the paths of the ice, and because of the greater volume of water skirting the ice front there on the south. On the west, however, the greater maturity and therefore the greater width of the valleys of the western tributaries, like the White, Cheyenne and Grand, enabled the ice to push westward easier than before. At any rate the de-

[6] *Bull. G. S. A.*, Vol. 23, pp. 463–470.

posits, moraines and till, show that the ice pushed westward up each of the valleys nearly to the line of the present Missouri. In other words, the ice filled the present James River valley so completely that all the western streams were dammed and the waters rose in each till an outlet was found southward. Between the Missouri and Cannon Ball and Grand rivers the divides were low and of soft material. But between the Grand and the Cheyenne was a prominent ridge capped with Fox Hills sandstone rising over 2,000 A. T. North of this was formed Lake Arikaree, reaching up the line of the present line of the Missouri to or beyond the mouth of the Yellowstone. Into it at several points the ice sheet at its maximum dropped small icebergs, by which boulders were scattered over the bed of the lake, and particularly on its southern margin, which is now in places marked by a line of boulder-capped buttes and ridges apparently corresponding to an old water level or lake margin.

The divide between the Cheyenne and White rivers was again comparatively low, but that between White and the Niobrara was again high, nearly 2,000 feet A. T., and capped with Tertiary sandstone. Through this an outlet was started which now is an imposing gorge, 750 feet deep. The ice also blocked the Niobrara from Springfield to Yankton, but did not force it over the divide southward as during the Kansan stage. Instead the river was crowded up on the south side of its valley where it excavated so deep a channel before the retirement of the ice that it became permanent.

So we have the present course of the Missouri from Ft. Stevenson to Yankton as a direct result of the Wisconsin stage of the ice sheet, as the course from Sioux City to Nebraska City was probably determined by the Nebraskan stage and from Nebraska City to Kansas City and possibly to its mouth by the Kansan stage.

G. DURING THE RECESSION OF THE WISCONSIN STAGE

The Wisconsin was the last great invasion of the ice sheet, and its recession was long and marked by long pauses, when belts of knobs and ridges of débris were dropped from the nearly stationary edge of the ice. The first of these and the most voluminous was formed a few miles within the maximum extent of the ice. Before the next was formed there was recession far within the line of the second moraine and then an advance and a pause to form the second moraine. So that the Wisconsin stage had many substages similar to the stages already reviewed except that they were shorter and with ever-waning extent. During the recession from the first moraine there was the unloosing of great volumes of water as there was at the close of the Kansan, laden with much sediment, coarse and fine. The coarse dropped near the edge of the ice-formed valley trains, the fine, carried far, formed a deep accumulation of silt, particularly in broader and stiller portions of the streams. Such deep deposits are found well-preserved at many points. Their upper surface seems originally to have been nearly flat like a river terrace, but is now not only deeply eroded, but is more or less increased in height by the wash from the upland back. The lower limit is of course uneven, but usually is only a few feet above the present level of the streams. This deep silt and sand deposit is frequently from 80 to 120 feet deep. It closely resembles the loess often found on the uplands in the vicinity. In fact they have often been confused, nor is it any wonder.

This lower loess or early Wisconsin flood deposit is finely exposed at Kansas City,

Kan., also in the bench along the north side of Kansas City, Missouri. At Leavenworth, St. Joseph, and south part of Sioux City, besides several less conspicuous points between, and further down the river. Similar deposits are found in the lower part of the Kansas River near Edwardsville, Holliday and Bonner Springs. Here it is due to back water from the Missouri, and the character and color differ from those of the Missouri River deposit.

After considerable examination I have no doubt that the similar terraces in western Iowa along the streams which headed near the edge of the Wisconsin ice are to be referred to the same cause. I refer to the terraces on the Boyer, Soldier and Maple. The absence of such along Mosquito, Nishnabotna and Nodaway confirms this conclusion. They were too far away to share in the floods from the Wisconsin ice.

Similar floods may have attended similar recessions from later moraines, but they were less effective, and after the third or fourth the ice retired too far away to affect the Missouri notably. Numerous lower terraces are found along the Missouri and its tributaries, which record such stages which attended the gradual deepening of their channels in the 15,000 or 60,000 years since.

In the recession of the ice, glacial lakes were formed from time to time. Lake Dakota was formed in the central part of the James River valley, while the fourth moraine was forming. It became nearly filled with a fine silt closely resembling loess.[7] Later Lake Agassiz occupied the Red River valley, but it was beyond the scope of our subject.

I leave the subject with you. If I have made any point clearer or suggested a thought which may lead to further light I shall be well satisfied.

It may gratify our national pride a little to see how cleverly nature, not long ago, changed so much of the drainage which was sweeping the rich soil of our great plains into the British dominions, so that it was permanently diverted into our borders.

From this sketch, we see how nature has wrought the course and character of the greatest stream on earth, and one of the most important. It may not be called as historic as others, for its history is yet to come. Who can doubt that it is destined to be associated with some of the mightiest and most far-reaching events of the future,

J. E. Todd

University of Kansas

[7] *Iowa Acad. Sci.*, Vol. XIII., p. 187.

BENJAMIN OSGOOD PEIRCE

The death of Professor Benjamin Osgood Peirce at Cambridge on January 14 removes before his time one of the most valued members of the Harvard faculty and one of the most scholarly of American physicists. Having been asked by the editor of Science to contribute an obituary note, although feeling that one of his colleagues could do it in a more accurate manner, I could not forego the melancholy satisfaction of paying a personal tribute to the best of teachers and the cherished friend of thirty years. Peirce came to Harvard as instructor in the same year as the writer as a freshman, and the admiration he then inspired has only grown with years.

Peirce's first ancestor in America was Richard Norman, who came to Gloucester in 1623. His great-grandfather, Benjamin Peirce, was killed at Lexington. From him was also descended Benjamin Peirce, the distinguished mathematician. On his mother's side Peirce was descended from ship-owners in Salem. Born on February 11, 1854, at Beverly, it was from such sterling stock that Peirce inherited the New England conscience and capacity for thoroughness which were his leading characteristics. He received an excellent preliminary education in the schools of Beverly, and afterwards prepared himself for college, with plenty of Latin, Greek and mathe-